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Organizational Structure, Information Technology and R&D Productivity

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ABSTRACT

To improve R&D productivity and performance two types of communication must be managed properly. First there is communication which is required to coordinate the many complex tasks and subsystem interrelations that exist on an R&D project. Second, there is communication which insures that the technical staff of the project remain current. Organizational structure can be employed to achieve either of these goals. Since different structures are needed for the two, it is important to consider the situations in which one or the other dominates. A tradeoff is necessary. Project organization facilitates task and subsystem coordination. Functional organization connects engineers more effectively to the technologies upon which they draw. The manager must determine the situations in which one or the other goal dominates and employ the organizational structure appropriate to that goal. The present paper provides three parameters which can be used to characterize project situations and guide the decision on organizational form. In addition, there is the possibility that improvements in information technology will be able to substitute for one of the two organizational forms and allow greater use of the other, thereby easing the organizational tradeoff.

An overwhelming body of research evidence indicates that the most direct route to increasing research and development productivity is through developing good technical communication within the R&D organization itself (Table I). These studies show very clearly the relationship between R&D performance, particularly project performance, and internal technical communication.

There are, however, two kinds of technical communication between which a balance must be reached to achieve optimal organizational performance. The first of these is similar to work-related communication in any kind of organization. It is that communication which, while technical nature is required to coordinate the tasks of the organization. It transmits the results of one engineer's work to another engineer whose work depends on those results. This communication, which is directed toward coordinating tasks, exists in every organization, and is not unique to R&D. In the R&D laboratory, however, there is an additional layer of communication. The second type of

Table I

Technical Communication Within the Laboratory and R&D Performance

Study	Results
Allen (1964)	Positive correlation between internal technical communication and technical quality of proposals.
Allen (1977)	In cases of engineers working on identical problems in different organizations, higher performers obtained higher proportion of ideas from colleagues within the organization.
Goldhar, et. al. (1979)	Award winning innovators cited most important source of information in developing innovation as communication with colleagues within the organization.
Baker, et. al. (1967)	Successful ideas for new products originated primarily within the organization.
Allen, et. al. (1980)	Higher performing product and process development teams communicate significantly more within the organization.

communication keeps engineers abreast of developments in their technical specialties. In the short run, the work may not necessarily require it but in the long run this type of communication can have a very marked effect on the quality of that work.

This paper will treat the tradeoffs between the two types of communication and the ways in which these tradeoffs have been reflected in management's choice of organizational structure.

Managers of research and development have been extraordinarily creative in developing new organizational forms to meet changing needs over the past 30 years. These forms are many and varied. Some are even artistic!

All of these many organizational forms can, however, be analyzed into combinations of two fundamental types. One type attempts to match the structure of the input to the R&D organization; the other looks to the output.

Input-Focussed Organization

The principal input to an R&D organization is technical and scientific knowledge. This type of knowledge is organized around disciplines, sub-disciplines, technologies and technical specialties. To effectively manage this input many R&D organizations have structured themselves in a compatible manner, i.e., around disciplines, technologies or technical specialties. This is a very old form of organization. Indeed, universities have been organized in this manner since antiquity. Structuring the organization in this way provides a strong connection to the knowledge base underlying the organization's work. In an industrial laboratory, it ties engineers to their technical specialties in the most effective manner. Engineers keep up with developments in their specialties far more through discussion with colleagues than by any other means (Allen, 1977). The input-focussed, or functional, organization enables them to do this effectively by placing them in organizational and often physical proximity to colleagues, who share their technical specialty. Of course, by focussing so strongly on inputs, this form of organization almost necessarily creates difficulties on the output side (Figure 1).

The output of an R&D organization does not normally take the form of disciplines or technical specialties. Output is generally in the form of designs for new products or new processes. Such product and process designs often require the simultaneous application and coordination of a number of disciplines or technical specialties. This coordination problem can be severe in a functional organization. The specialized functional departments or groups present a barrier to coordination, that can become very difficult to manage.

Output-Focused Organization

In response, a new form of organization evolved. In this type of organization, engineers are taken out of their

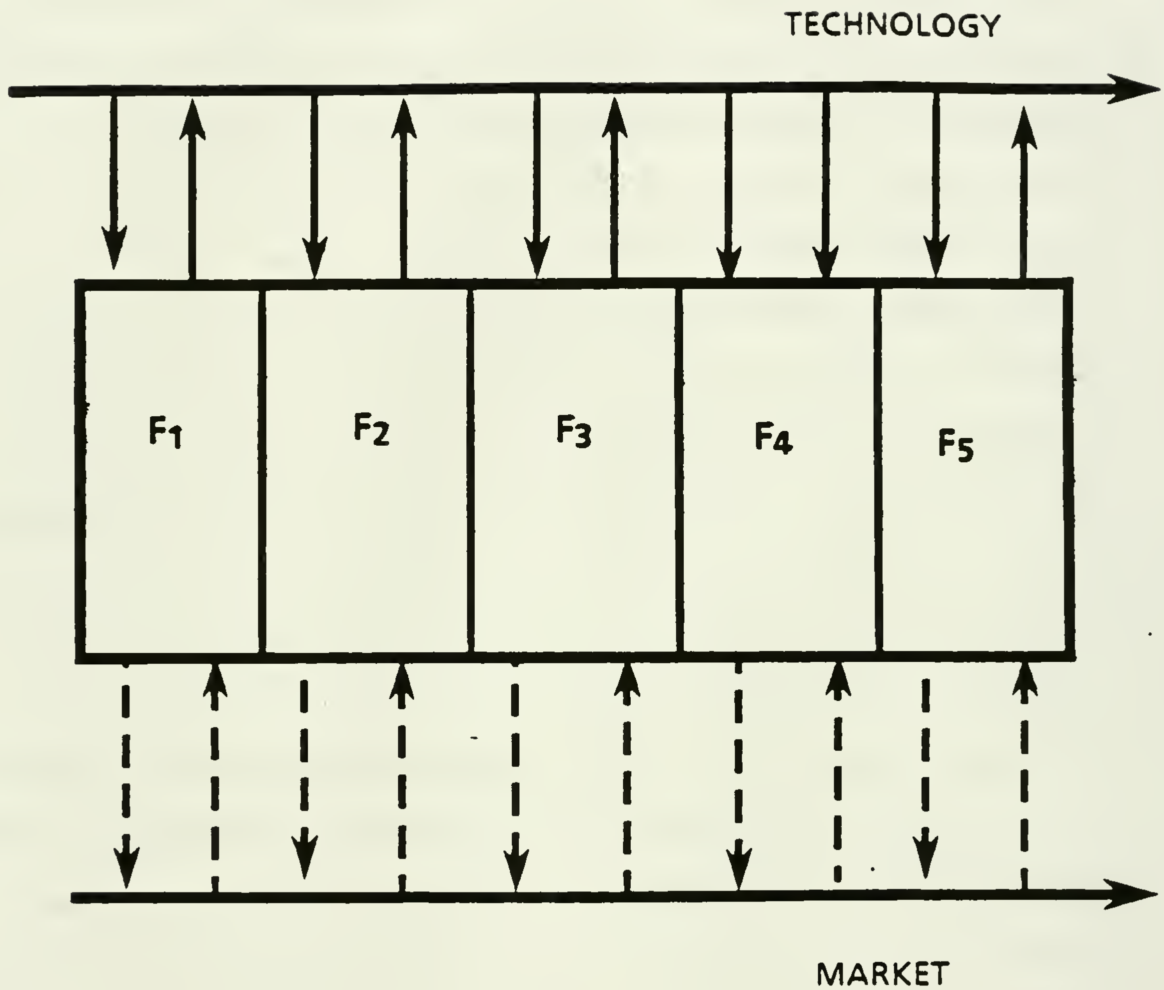

Figure 1. The Functional Organization and the Innovation Process

functional departments and report directly to a project manager. In most cases, their work stations are also physically moved, so that all engineers on a given project are located, with the project manager, in the same area of the facility.

The project organization solves the coordination problem by insuring that everyone shares the same reporting relationship, by providing the project manager more direct authority and by bringing all of the engineers together in the same organizational and physical location. This essentially satisfies the output requirements of the organization (Figure 2). In doing so, however, it creates a new problem on the input side. Knowledge, even scientific and engineering knowledge, is not organized in the form of projects. It is organized, as stated earlier, in the form of disciplines or technical specialties. There is, therefore, a discontinuity or mismatch at the input to an R&D organization that is organized around projects. Engineers find it more difficult to stay current with developments in their specialties, and the organization over the long term becomes isolated from its supporting technologies. A number of organizations, particularly in aerospace and electronics suffered this problem in the 1960s and 70s.

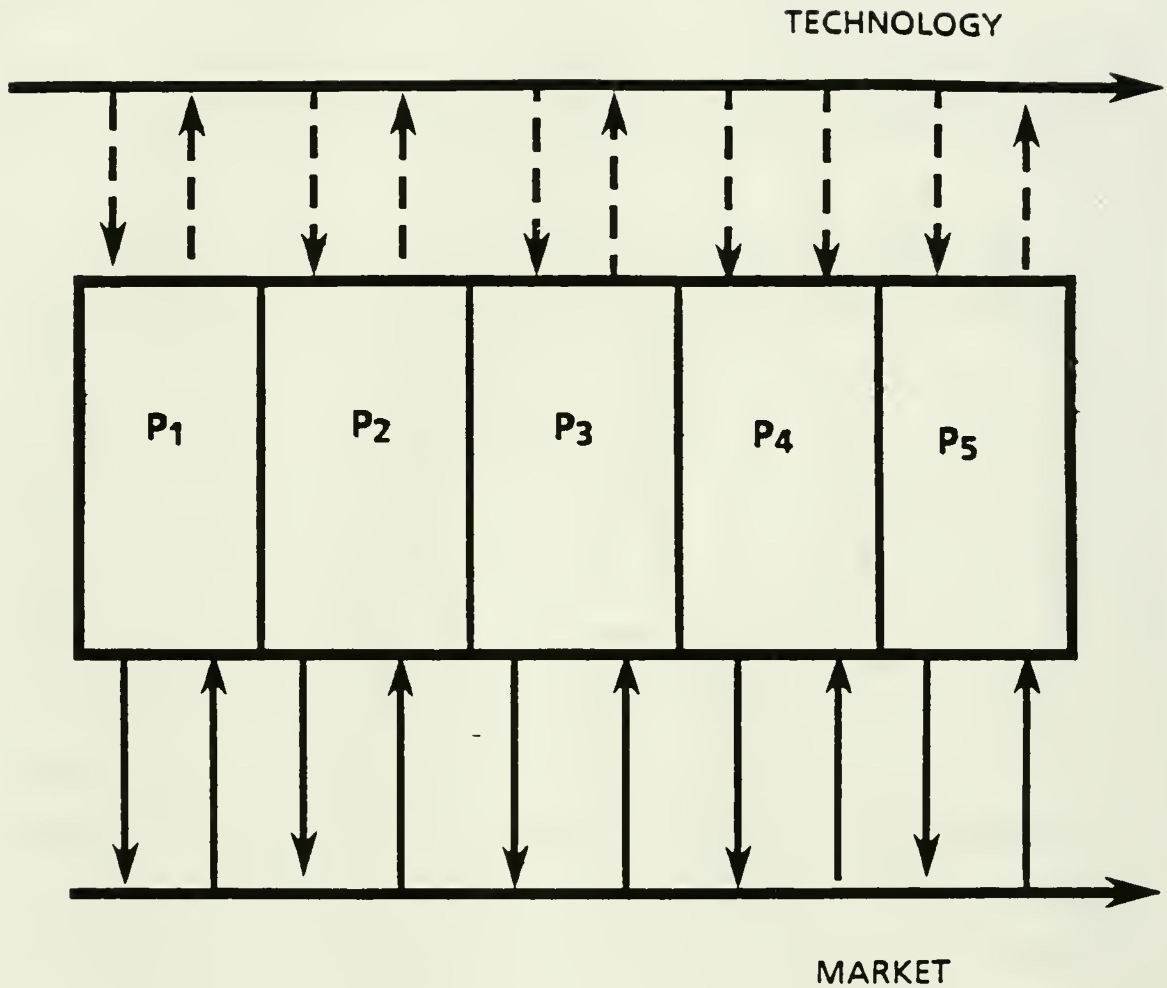

Figure 2. The Project Organization and the Innovation Process

The Trade-Off Between Project and Functional Organization

Summarizing the discussion to this point, it can be seen that there are two conflicting goals which an R&D organization must seek to fulfill:

1 The activities of the various disciplines and specialties must be coordinated in order to accomplish the work of multidisciplinary projects.

2. Projects must be provided with state-of-the-art information in the technologies they draw upon. This, as we have seen, is best accomplished through face-to-face communication.

It is the trade-off between these two goals that has resulted in the various organizational forms used in R&D. Functional management, in which the laboratory is organized around disciplines or technical specialties, best accomplishes the latter of the two goals. Project management, in which all specialists assigned to a project report directly to a single person, the project manager, and are usually moved into a single physical location, best accomplishes the former.

Most other forms of R&D organization are a variant or combination of these two forms. Over the years there have been many proponents of one or the other of the two. There has been very little real understanding of the fundamental principles underlying choice of structure.

The Organizational Structure Space.

If one examines the goals, outlined above, for the two types of organization, it is clear that the importance of the goal of connecting engineers with their knowledge base will be a function of the rate at which that knowledge is changing.

Technologies can be arrayed at least roughly according to the rate at which they are developing. Certainly the more mature technologies are progressing in a relatively slow manner. Other technologies are more dynamic. This parameter, the rate of change of knowledge (dK/dt), is one coordinate of a space, which will be used to determine the decision on organizational structure (Figure 3). The other coordinate is project duration, or more precisely, the duration of an individual's assignment to the project (T_i). The logic behind this is very simple. On a short project, an engineer, even one working in a very dynamic technology, will be unlikely to lose touch with developments in that technology. On a long project, that same engineer is in very real danger of falling behind. On a long project, engineers become very narrowly focussed on the problems inherent in that project and come to know the application of their technologies to those problems extremely well. But since they are organizationally separated from colleagues in their specialty, they lose contact with other developments in those technologies.

In staffing a project, individuals and their situations often fall at a variety of points in the Organizational Structure Space of Figure 3. A given project might employ a mix of engineers, some with relatively stable technologies and long term assignments, others with dynamic technologies and long or short assignments to the project. These situations are represented by appropriate positions in the Organizational Structure Space.

Project and Functional Regions.

Looking at the positions of points in Figure 3, it is obvious that for situations in the lower left portion of the space, project organization should produce better results. In those situations, the benefits of better intra-project coordination should more than offset any loss of external technical support. Project assignments in that region involve engineers, who are drawing on relatively stable technologies and who will be working on the project for only a short period of time anyway. Engineers in this situation are unlikely to suffer any loss of performance as a result of losing touch with developments in their specialties.

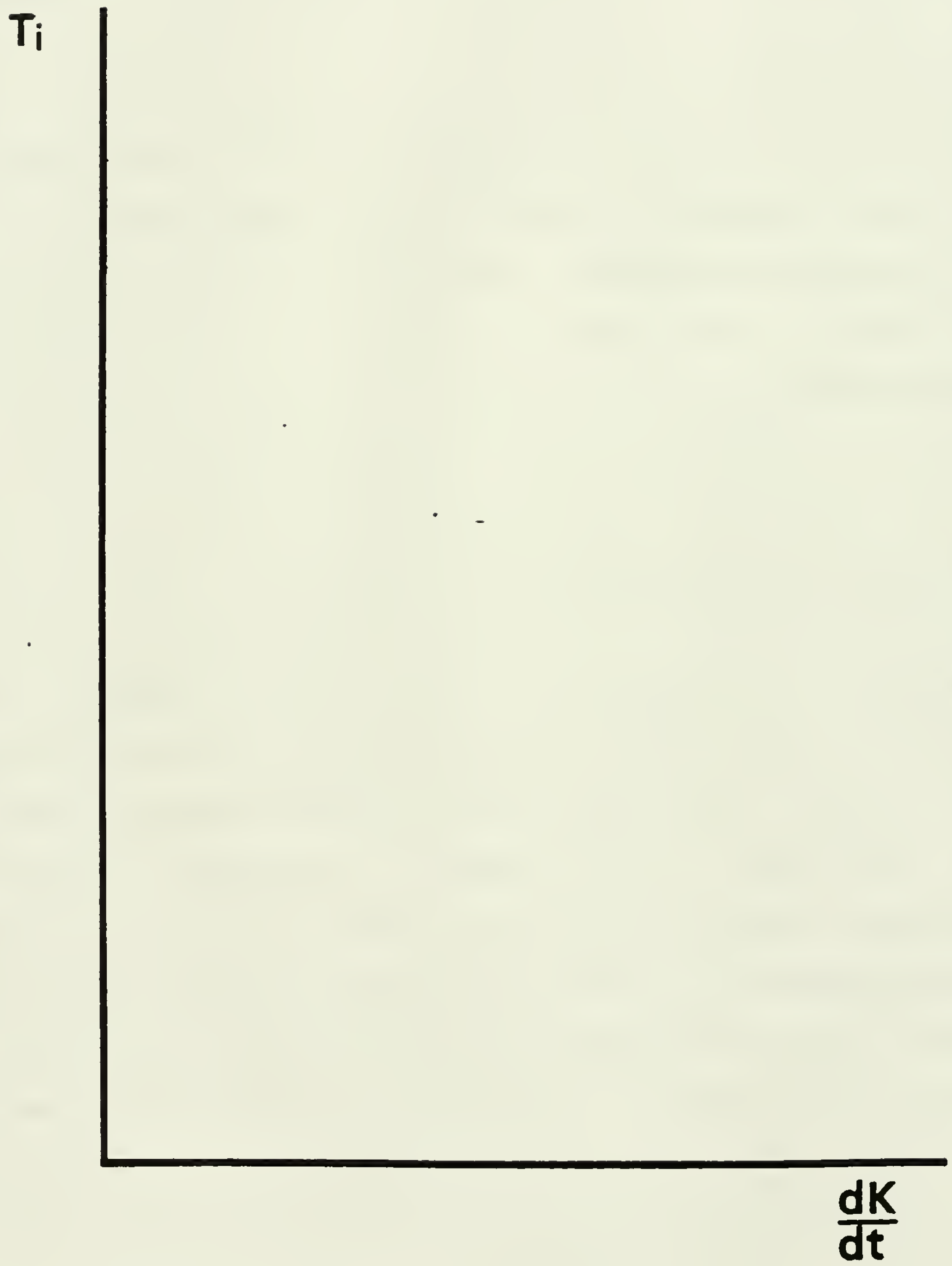

Figure 3. Organizational Structure Space

On the other hand, engineers whose situations fall in the upper right hand region of the space, should perform better under functional organization, in which they remain in their functional departments with a matrix relationship to the project. In such situations, the technologies are changing at such a rate and the assignments are sufficiently long that the engineers are in danger of falling behind developments in their technical specialties. The functional organization, by grouping the engineers with others who share their specialties, lessens the likelihood of this happening. The best way to keep engineers informed is to make it easy for them to have direct contact with colleagues who share their specialty (Allen, 1977). The functional organizational buys this capability at the cost of greater difficulty in project coordination. In the upper right hand region of the space, the tradeoff tilts in the direction of favoring the benefit of improved technical support through colleague contact over the cost of difficulty in coordination.

The Organizational Structure Space can thus be sub-divided into two regions. For situations in the upper right region, functional organization is the preferred structure. For situations in the lower left region, project organization will produce better results (Figure 4). On many projects, assignments will fall in both regions. There is no reason why both forms of organization cannot be used simultaneously. Those engineers whose project assignments are of short duration or who are drawing on relatively stable technologies, should be formed into a project team reporting to the project manager and housed together in the same part of the facility. Those whose assignments are to be of longer duration or who are drawing on the more dynamic technologies should be left in functional departments with colleagues who share those technologies. Their relationship to the project manager should take a matrix form.

While all of this may seem intuitively obvious, normal industrial practice generally follows a completely opposite course. The decision on organizational structure is usually made on the single dimension of project duration, without even adding the complication of varying lengths of assignment for different engineers, let alone the nature of the technologies involved. If a project is expected to run a relatively short period of time (perhaps six months or a year) engineers will normally be left in their home departments. If a project is to run several years a project team is usually formed.

The Matrix Organization

The parameters, project duration and rate of change of the knowledge base in the source technologies, can now be used to determine organizational form. There have been, in the past, some rough rules for location of people in a matrix organization. The project manager or program manager's office generally contains some administrative and "systems level" personnel, the latter being responsible for system integration and resolving interface problems among the subsystems. These functions still need to be performed and these types of people should be located in the project team. However, they are not the only engineers who should be so located. We now have a firmer theoretical basis for organizational location. Engineers whose situation falls in the area to the left and below the diagonal in Figure 4, will be more effective when organized in a project structure. In such situations, the benefits of better internal coordination that are available under project management outweigh the benefits of improved disciplinary support that are available with functional organization. In the area above the diagonal, functional organization is preferable. Here, disciplinary support is needed to such an extent that it becomes reasonable to sacrifice some internal coordination for it. Certainly the administrative personnel belong in the program management office (Marquis & Straight, 1965). In addition to them and to the systems people, however, many of the technical specialists can be located there as well. The decision will be based on estimates of the two parameters. Organizing in this manner will allow better coordination within the project without unduly sacrificing the project's connections to its technological base.

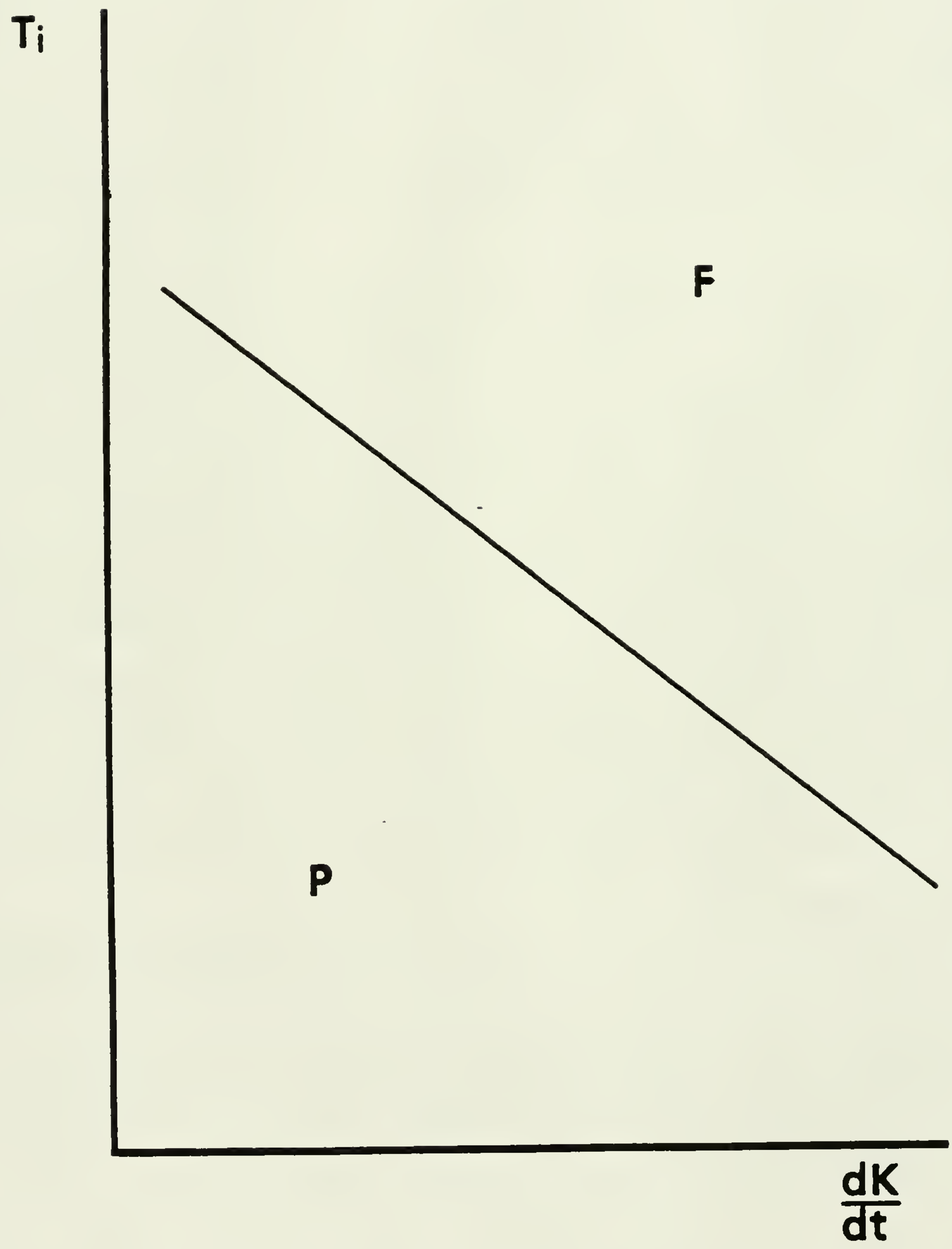

Figure 4. Division Into Project and Functional Regions

Subsystem Interdependence

A third parameter determines the position of the line separating the project and functional regions in the space of Figure 4. The degree to which work is interdependent among different portions of the project determines the degree to which task coordination is necessary. The extent to which work on one subsystem or problem depends upon progress in another subsystem or problem area and the complexity of the interface requirements among subsystems and problem areas determine the severity of the project coordination problem. It is the need for coordination of tasks within a project that calls for the use of project organization. Therefore, the magnitude of the subsystem interdependencies will determine the extent to which project organization is required, to provide the coordination needed to manage these interdependencies. Thus the position of the line separating project region from the functional region in Figure 4 will be determined by the magnitude of the subsystem interdependencies in a given project (Figure 5).

When subsystem interdependencies are high, project organization will be required for a larger proportion of the personnel. When these are low, it becomes much easier to manage the project within a matrix (functional) structure.

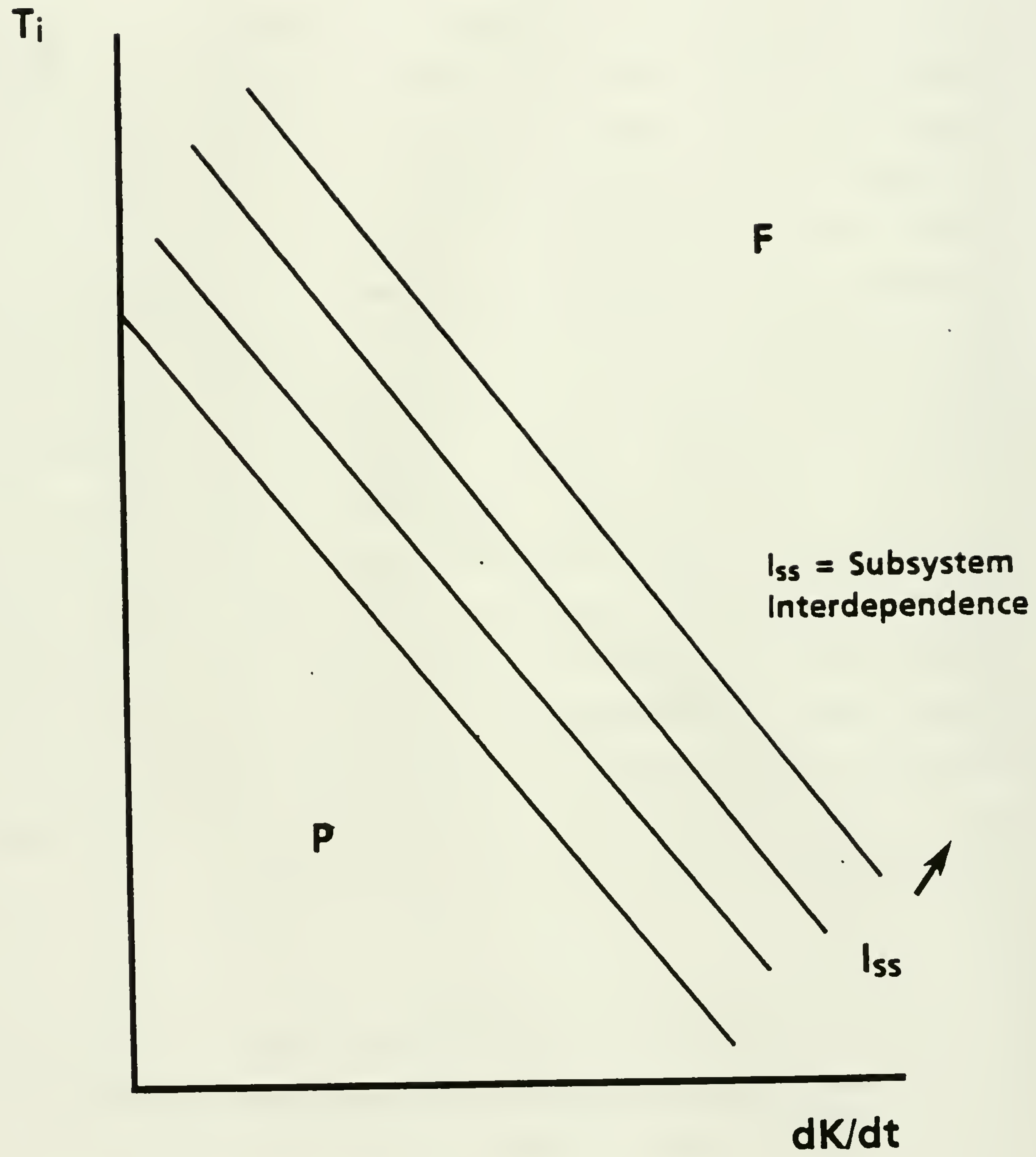

Figure 5. The Effect of Subsystem Interdependence.

Determination of Organizational Structure

So the optimal form of organization for the research and development laboratory is determined by three parameters. The rate of change of the knowledge base (dK/dt) determines, in part, the extent to which engineers must be organized in a manner to assist them in keeping current through colleague contact. The interdependency among subsystems and problem areas within the project (I_{ss}) determines the extent to which intra-project coordination is necessary and the frequency with which it is required. Finally, project duration, or more particularly, the duration of assignment (T_i) for any specific engineer will determine the degree to which one must be concerned about the separation of that engineer from his knowledge base. Short term projects have little effect in this regard, long term project assignments can have a serious effect.

By estimating the situation on each of the three parameters for a given set of project assignments, a project manager can determine the extent to which the project will benefit from bringing engineers directly into the project team or by leaving them in their home departments and creating a matrix relationship to the project.

The Impact of Improvements in Information Processing Technology

One cannot discuss organizational communication these days without at least speculating about the impact that the explosive developments in information technology will have on such communication. Certainly, as human communication is augmented by improved technology, some of the functions now assigned to organizational structure will be assumed by that technology. Advances in Information Technology may be seen as substituting for organizational structure in either or both of two ways. First, one could argue that improvements in information technology will make it easier for engineers to keep up to date. Advances beyond contemporary document retrieval and selective dissemination systems, incorporating artificial intelligence techniques (Malone, 1986) will make it easier for engineers to use the literature to keep in touch with developments in their specialties. In this way, the information system accomplishes a goal which was formerly achieved through organizational structure. The functional organization has as its goal the improved coupling of engineers to their supporting technologies through colleague contact. The information system through improved access to the literature might obviate the need for colleague contact and thereby accomplish the goal for which the functional form of organization has been traditionally used.

On the other hand, improved systems for project coordination are being developed which will make it easier for project team members, as well as the project manager, to stay current with progress on sub-problems, changes in subsystem design and modifications to interface specifications.

In this way, the information system also attains a goal which was formerly accomplished through organizational structure. The project structure has as its goal improved intra-project coordination. This is accomplished organizationally through better direct contact among project team members. The information system, through its improved coordination capabilities, obviates the need for as much face-to-face contact among project team members and thereby accomplishes that goal for which the project form of organization was originally developed.

Available research evidence would incline one to believe that the second of these effects will dominate. The reasons for this are straightforward. For the foreseeable future, information systems directed toward connecting engineers to a knowledge base will be limited by the nature of that knowledge base. Information systems can presently access only that portion of the knowledge which is contained in the form of documentation. The documents, books, journals, papers and so on may be stored magnetically, but at some point they must be converted to print for the engineer to read. There is a very large body of research (Allen, 1977) which indicates that, while the printed word might be a satisfactory medium for basic research scientists it is, and will likely remain, a little used source of information for engineers. No matter how well this information is stored and delivered to the engineer, it must still be converted ("translated") into a form which is seen as relevant to, and understandable by him. So information technology will be severely limited in aiding the engineer by the form in which it ultimately delivers technical information. For all these reasons, the principal means for communicating knowledge to engineers is and will remain the spoken word. Engineers must be able to talk directly to other engineers to stay current with their technology. The functional organization does this well and there is little chance of information systems assuming this function in the foreseeable future.

On the other hand, information about project or subsystem status, progress on particular technical problems, changes in product configuration and so on can be more easily communicated by information systems and readily understood by engineers engaged in a project. In this sense, information technology, by providing improved means for updating and transmission of this information should have a significant impact. At present, most projects are coordinated, as they have been for years, by means of periodic review meetings and written status reports or memoranda. There is absolutely no reason why such devices cannot be put "on-line". The software for conferencing and for "many-to-many" reporting exists (Stevens, 1981; Livingston, 1984) and is rapidly being improved. As such electronic means for project coordination advance, the problems associated with coordinating project work across a matrix organization structure should be diminished considerably. In other words, information technology will be accomplishing the major goal for which project organization was developed. Information technology, in this way, can be viewed as a substitute for the project form of organizational structure.

The impact should be greater for those specialties which are changing rapidly and which will therefore benefit more from the advantages of functional organization. Those project participants who draw on more stable specialties do not need to associate to the same degree with similar colleagues to stay up to date. So the impact of improved coordination through advances in information technology will be greater for the more dynamic technologies.

The net effect on the theoretical space of Figure 4 will be to move the dividing line between the project and functional regions in such a way that the functional region is increased. Since the effect on more dynamic specialties is greater, this will result in a change in the slope of the dividing line between project and functional regions (Figure 6). Functional

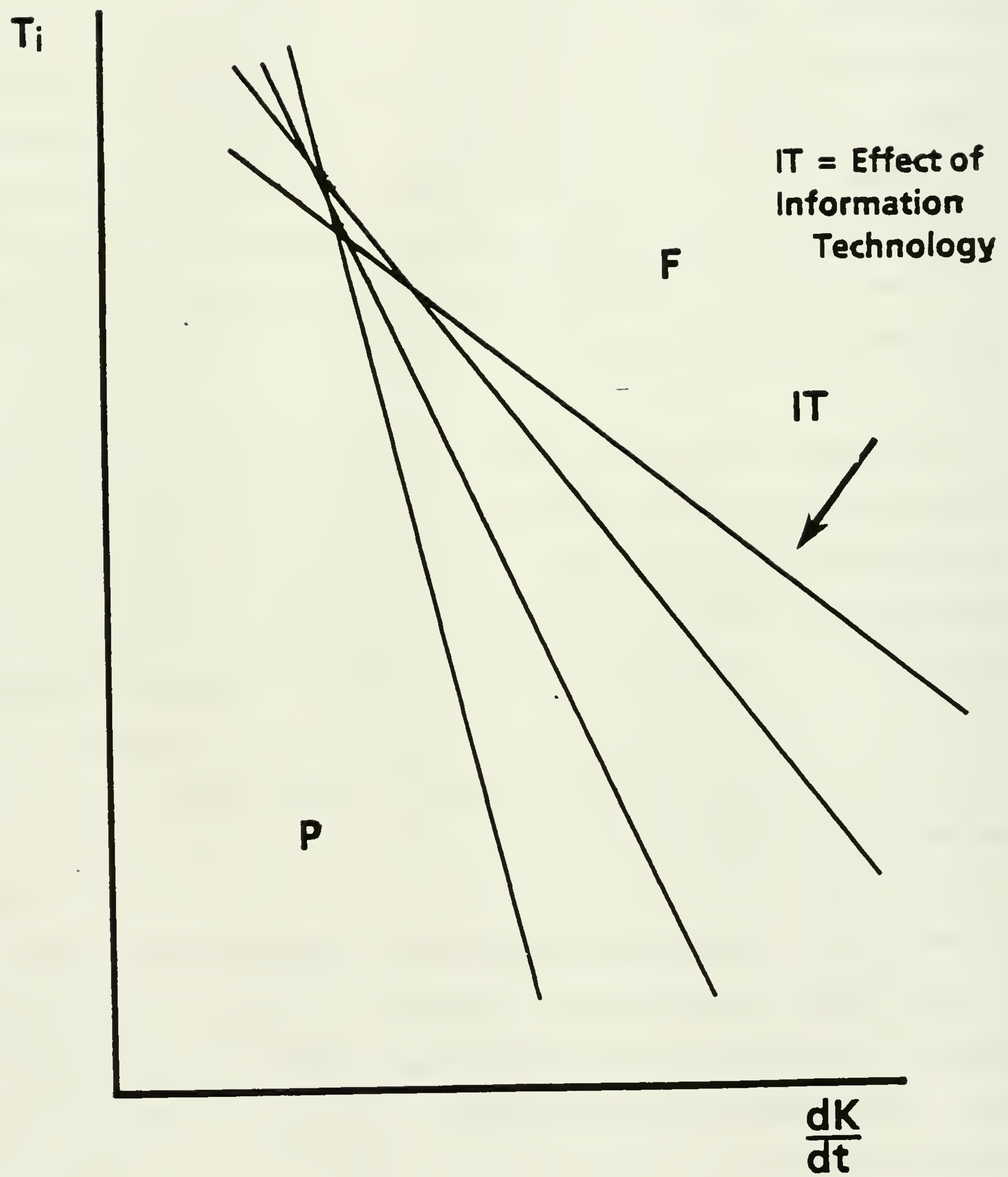

Figure 6. The Effect of Information Technology.

(matrix) organization will become the more appropriate form for a greater number of situations.

Conclusions

To improve R&D productivity and performance two types of communication must be managed properly. First there is that communication which is required to coordinate the many complex tasks and subsystem interrelations that exist on an R&D project. In addition, in R&D laboratories, there is a second layer of communication which insures that the technical staff of the project remain in close contact with developments their technical specialties. Organizational structure can be employed to achieve both of these goals. Since different structures are needed for the two goals, it is important to consider the situations in which one or the other goal dominates. A tradeoff is necessary. Project organization facilitates task and subsystem coordination. Functional organization connects engineers more effectively to the technologies upon which they draw. The manager must determine the situations in which one or the other of these two goals is more important and employ the organizational structure appropriate to that goal. The present paper provides three parameters which can be used to characterize project situations and guide the decision on organizational form. Finally, there is the hope that improvements in information technology will be able to substitute for one of these organizational forms and allow greater use of the other, thereby removing much of the conflict inherent in the organizational tradeoff. It would seem likely, at this time, that information technology will prove more capable of improving project coordination than it will of providing state-of-the-art technical information to the engineer. It will thus serve as a substitute for project organization and allow greater and easier use of functional organization. Used effectively, information technology may even "civilize" the matrix.

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